TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 735

THE HIGH-SPEED TANK OF THE HAMBURG SHIPBUILDING COMPANY

By G. Kempf and W. Sottorf

Werft-Reederei-Hafen, June 1, 1931

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The heavy demand, both domestic and foreign, on the activity of the laboratory necessitated in 1926 the introduction of a permanent second shift. Much time was taken by seaplane hull and float investigations which, on account of numerous variables affecting the result, required extensive model tests at high speeds. Shortage of time gradually prevented attending to these tests with all the care which they require. Under these conditions practically no time could be devoted to research work for shipbuilding and seaplane-construction purposes.

The original large water tank was built in 1913-14 for ship-model investigations which were usually made at speeds not exceeding 3 m/s (9.8 ft./sec.) and only exceptionally reaching 6 to 7 m/s (19.7 to 23.0 ft./sec.) Under these conditions a maximum carriage speed of 7 m/s then appeared sufficient. It was subsequently increased to 10 m/s (32.8 ft./sec.) by the installation of new carriage motors (fig. 1).

The necessity of a further increase of the speed was felt in many scientific and especially seaplane-float investigations. For the latter, the model scale λ is a function of the maximum carriage speed v_{max}, according to Froude's model law

$$\lambda = \frac{V_s^{2}}{v_{max}^{2}} \text{**}$$

The original maximum test speed of 7 m/s, with a square of 49, was increased, by transformation of the carriage, to

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*"Der neue Schleppkanal für hohe Geschwindigkeiten der Hamburgischen Schiffbau-Versuchsanstalt." Werft-Reederei-Hafen, June 1, 1931, pp. 175-180.

**v_{max} = carriage speed = starting speed of the model, V_s = starting speed of the full-sized float, λ = scale of model.

10 m/s, with a square of 100. The take-off speeds of actual seaplanes average 40 m/s (131.2 ft./sec.) with squares of 1,600. The model scale was therefore increased from 1/32 to 1/16. On this scale, the models of light seaplanes are very small and a direct conversion of the test results to the actual seaplane is no longer possible, as shown by special investigations of the scale effect on the spray formation and of the Reynolds Number on the friction. Under these conditions the speed had to be greatly increased for testing large models.

Another point had to be taken into consideration for the construction of a new high-speed tank. Such research work requires continually revised methods of measurement and much time for the installation of apparatus and for preliminary tests which extend usually over several months. A special tank should be available for such tests. Such a tank, not having to share the general expenses of the whole establishment, would permit conducting the above tests more thoroughly and carefully without increasing the cost. A reduction of the cost of float investigations is particularly desirable to permit more exhaustive tests to be made. Float tests are more comprehensive than the normal towing tests of ships, while their cost, in comparison with the cost of construction of the finished object, is less favorable than is generally the case in ship investigations.

In addition to testing large float models at high speeds and developing better and cheaper means of investigation for comprehensive research work, without interfering with current and usually urgent ship-model tests, it was also proposed to attain test speeds of the order of 40 knots, corresponding to the maximum speed of large ships, for the investigation of navigation problems. The true model resistance and all accompanying phenomena could thus be studied. For inland navigation problems, the whole length of the new tank should be available for tests in shallow water, in addition to the shallow tank and to the rather short experimental portion of the large tank of 8 m (26.25 ft.) width.

As a result of the above considerations, the idea of equipping the old tank with a fast carriage was abandoned and the construction of a new high-speed tank decided on instead. Ground was available on the west side of the old building, of which the new structure forms an annex, its cost being therefore comparatively small. The construction was started in May 1930 and completed in May 1931.

The funds were furnished by the government, the state of Hamburg, and the Society of the Friends and Promoters of the Hamburg Hydrodynamic Laboratory which obtained substantial gifts and loans.

DESCRIPTION

The new tank has a length of 322 m (1,056 ft.), a width of 5 m (16.4 ft.), and a depth of 2.5 m (8.2 ft.) to the brim. The carriage track is not laid on the tank walls but alongside on posts (fig. 2). The average distance between the double or single posts is 8.85 m (29.0 ft.). They are connected by underground beams and form, with the rails, a series of strong frames. The tank has a flat bottom and is independent of the rail track. Inasmuch as the brim of the tank is 1.3 m (4.3 ft.) above the ground, the tank lies above the level of the ground water and its pressure does not exceed that of the excavated earth. Therefore, a sinking of the tank need not be feared.

Cross-Sectional Dimensions of the Tank

In order to keep down the weight of the carriage and the cost of constructing the tank, the cross section does not exceed the dimensions required for the special purposes of the tank. On the basis of a theoretical study by Glazebrook and of experimental data from Gebers, the following dimensions were adopted in conformity with the largest proposed seaplane design known at the present time, that of the Rumpler transatlantic flying boat, on a 1:6 scale: width 5 m (16.4 ft.) and depth 2 m (6.56 ft.), subsequently changed to D = 2.5 m (8.2 ft.). The influence of the tank walls on the test results was determined by special tests.

1. A float of 17 m (55.8 ft.) length and 1.6 m (5.2 ft.) width, tapered at both ends, was tested in drafts of 0.07 m (2.75 in.) and 0.17 m (6.7 in.), corresponding to displacements of 1,333 kg (2,939 lb.) and 3,350 kg (7,385 lb.), respectively, in water of 0.7, 1.35, and 2 m (2.3, 4.4, and 6.5 ft.) depth. The test run begins in the large tank of 16 m (52.5 ft.) width and 6.75 m (22.1 ft.) depth, the cross section of the water being 92.7 m² (997.8 sq.ft.). The cross section of the float is 0.112 m² (1.2 sq.ft.). For a ratio of

$$\frac{\text{tank cross section}}{\text{float cross section}} = 827,$$

the cross section of the tank can be taken as equivalent to an unrestricted cross section and the resistance determined in the large tank, with the resistance in unconfined water.

Following the measurement in the large tank, the resistance is again measured at the entrance of the small tank which has a width of 8 m (26.2 ft.) and successive depths of 0.7, 1.35, and 2 m (2.3, 4.4, and 6.5 ft.). The resistance increment in shallow water is the difference between the two measurements. In figure 5 the resistance increment α, for runs in shallow water, is plotted in percent of the resistance in unconfined water against the carriage speed v as abscissa. Thus

$$\alpha = \frac{W_z}{W} 100^*$$

The resistance increment has a maximum value shortly before reaching the speed of the tank wave $v = \sqrt{gWT}$. The following maximum values of α are obtained for a draft of 0.07 m (2.75 in.):

WT	$\frac{WT}{Tfg}$	α_{max}
0.7 m	10.0	12.7 percent
1.35 "	19.3	4.4 "
2.0 "	28.6	1.4 "
2.5 " extrapolated	35.7	0.6 "

WT = water depth. Tfg = draft

It then had to be investigated as to whether the maximum resistance increment is a function of WT/Tfg only, or whether a different α value would be obtained for the same WT/Tfg, if the depth of the water remained constant and the draft were increased.

To this end the float was loaded with ballast until its maximum draft of 0.17 m (0.558 ft.) was reached, which is practically the same as that of the Rumpler model. The investigation at WT = 2 m (6.56 ft.) revealed, in addition to a shifting of the maximum resistance values toward small speeds, an α_{max} of 6 percent against 10.5 percent by interpolation in the above test series for the corre-

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*W_z = resistance increment in confined water; W = drag increment in unconfined water.

sponding WT/Tfg. Hence, the maximum α value for WT = 2.5 m (8.2 ft.) is, by extrapolation, 4.7 percent.

2. The effect of the wall interference on the tank tests of a gliding craft was determined by testing a 1:6 scale model of the forebody of the Rumpler design, in the same way as the float, allowance being made, however, for the lifting effect of the wings. To insure similarity of widths in converting the results obtained in the small tank of 8 m (26.2 ft.) width to the new tank, all transverse dimensions were increased according to the ratio

$$\frac{\text{width of small tank}}{\text{width of new tank}} = \frac{8}{5}$$

The width of the model is then	1.066 m	3.5 ft.
Its mean draft	0.178 "	7.0 in.
Its length	3.033 "	9.95 ft.
Its displacement	358 dm^3	12.6 cu.ft.

The depth of the water in the small tank was 2.5 m (8.2 ft.).

Seven test runs were made with the model. Their results are given in figure 6. The resistance curve shows that the gliding model is less affected than the float by the tank bottom and walls. The principal effects appear before the maximum resistance is reached, namely, in a region where practically no tests are made, since the results are important only at maximum resistance and beyond, in the gliding condition. Should, however, an unaffected result in the above region be required, it can always be checked by a test in the large tank, since the speed range involved does not exceed 5.5 m/s (18 ft./sec.). This proves the suitability of the cross-sectional dimensions of the new tank.

The tank has a constant rectangular cross section throughout its whole length. It can therefore be used for all shallow-water tests by raising or lowering the water level to the required height. The measurement is then made from a special adjustable platform. This provides the laboratory with an additional tank for shallow-water investigation.

In the front end of the tank is built the adjusting basin of 3.2 m (10.5 ft.) width and 9.5 m (31.2 ft.) length, separated from the main tank by a lock gate. The inflow and outflow openings of the main tank are located in this space, so that the basin can be partly or entirely emptied when the gate is closed. Test installations for under-water investigations can thus be mounted beneath the carriage in the emptied adjusting basin. Large models are locked under the carriage by lowering the water level in the adjusting basin.

Carriage

The carriage (fig. 7) was designed on the following lines:

1. Although great lightness was sought, light-alloy construction could not be used owing to its high cost, danger of corrosion, and weakness of joints. Welded steel-tube construction, of the type successfully used in airplane construction, was adopted. Silumin castings are used for large parts (fig. 8).

2. The carriage has a completely streamlined covering reaching nearly down to the water level, in order to avoid the effect of air disturbances on the resistance and moment of the model. Tank measurements should give the water resistance and the corresponding hydrodynamic moment, while the air resistance and the aerodynamic moment, used in plotting the take-off diagram, are obtained by wind-tunnel measurements. The covering is also designed to protect the operators from the wind at high speeds. The point to which the covering can safely approach the water level was determined by preliminary tests.

3. The free space in the carriage, available for experimental purposes, has a length of 8 m (26.2 ft.), a width of 3 m (9.8 ft.), and a height of 2 m (6.5 ft.). A platform which can be shifted longitudinally 1.7 m (5.58 ft.) is hung in the experimental space. The platform carries the guiding and suspension equipment for the tests and supports an auxiliary platform on each side of the model, which is vertically and laterally adjustable and permits a very close survey of the water flow along the model.

Carriage speed.- As shown by studies of scale effects, the model scale should not be less than 1:6, because of

the relatively small sizes of seaplane floats and hulls, if a discrepancy of 5 percent between converted model results and their actual value is not to be exceeded. The discrepancy is due to the neglect of the difference between the specific friction of the model and that of the original. The difference increases rapidly for small scales.

The take-off speed of large flying boats lies between 30 and 40 m/s (98 and 131 ft./sec.) whence, according to Froude, the maximum take-off speed of models is $v = \frac{40}{\sqrt{6}} = 16.33$ m (53.6 ft.). The carriage was given a maximum test speed of 20 m/s (65.6 ft./sec.), providing for a sufficient speed reserve. This maximum speed will be often used in experimental research at large Reynolds Numbers.

The resistance of the streamlined carriage in the small cross section of the tank building had to be known for the determination of its characteristics. Two models of different carriage types were tested for this purpose.

The carriage model in the cross section of the tank building was tested in the shallow tank of the laboratory, as shown in figure 9. The drag was measured during runs in the open water of the shallow tank and in the cross section of the tank building.

In figure 10 the $C_W = \frac{W}{qBH}$ values are plotted against $R = \frac{vL}{\nu}$. *

A Reynolds Number of approximately 1×10^6 is reached during the measurements, while the carriage approaches 2×10^7 at 20 m/s (65.6 ft./sec.). Experience shows that a renewed increase of the C_W value does not usually take place at large Reynolds Numbers. The resistance may be overestimated, if ultimate C_W values are used for its determination.

Design 1, a comparatively blunt form, has an ultimate $C_W = 0.722$ in the cross section of the building. The in-

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*W = water resistance in kilograms; $q = \frac{\rho}{2} v^2 = 51\ v^2$ for water; B, H, and L = width, height, and length of the model in meters; v = carriage speed in meters per second; $\nu = 1.3 \times 10^6$ for water.

crease in resistance over that in open water is 82 percent. Design 2 is highly tapered at the rear. The decrease of the resistance in the cross section of the tank building equals approximately, in absolute value, the 17.5 percent reduction of the resistance in open water, the actual reduction thus decreasing to 9.5 percent. The comparison shows that no further material reduction can be achieved. Design 2, with a resistance of 197 kg (434 lb.), was adopted for the construction of the carriage.

Carriage drive.- The carriage is equipped with two direct current shunt motors of 40 kw. at $n = 1500/\mathrm{min.}$, driving the front wheels. It reaches a constant speed of 15 m/s (49.2 ft./sec.) in approximately 110 m (360 ft.) and can maintain it for 150 m (492 ft.) or for 10 seconds. Our experience shows that 9 to 10 seconds are required for a reliable measurement after the model reaches a constant speed.

If the speed of the carriage is further increased by electric means only, the time for the measurement gradually gets too short, since the acceleration is limited by the wheel pressure and by the friction coefficient between the wheel and rail.

An auxiliary acceleration device was therefore provided for speeds exceeding 15 m/s (49.2 ft./sec.). This device accelerates the carriage which reaches the maximum speed of 20 m/s (65.6 ft./sec.) after a run of only 80 m (262 ft.), and covers a test distance of 180 m (590 ft.) in 9 seconds, at a constant speed of 20 m/s. Of several methods tested, that of producing additional acceleration by a drop weight was adopted for the following reasons:

1. The acceleration is produced by gravity which insures reliable operation and uniform action.

2. Power is supplied during the start and retrieved during the slow return of the carriage. Thus, the maximum admissible current consumption is not exceeded.

3. The cooperation of the drop weight with the electric drive is simple.

4. Space requirements and cost are both small.

Assuming a constant acceleration, the mean speed of

the carriage is 10 m/s (32.8 ft./sec.), the acceleration 2.5 m/s² (8.2 ft./sec.²) and the starting time 8 seconds.

The total accelerated carriage weight is 5,150 kg (11,350 lb.), 3,700 kg (8,160 lb.) of which is supported by the driving wheels.

The total resistance shortly before the end of the acceleration period (v approx. 20 m/s) consists of:

Force of inertia	1,312 kg	2,892 lb.
Air resistance	197 "	434 "
Bearing friction	10 "	22 "
Model resistance (assumed)	100 "	220 "
Total resistance	1,619 "	3,568 "

The maximum force K exerted at the circumference of the wheel is μQ = 518 kg (1,142 lb.).*

The air and model resistances being constant, a constant force of 1,619 - 518 = 1,101 kg (2,427 lb.) must be exerted on the carriage during the period of acceleration, by an auxiliary accelerating device. This device is shown in figure 11. The well is located at the front end of the tank. An endless cable runs on either side of the carriage between the tank wall and the track, along the 80 m (262 ft.) distance of acceleration. The upper part of each cable carries a catch which fits into a thrust plate on the carriage. A pull-rope is connected with the lower part of each of the loops. It runs over the guide sheave A, over sheaves B and C of the double eightfold blocks, and over the second guide sheave A to the other side. The two branches S_1 and S_2 of the cable are automatically balanced about the fixed center sheaves C.

At v = 20 m/s, the final velocity of the weight is 2.5 m/s (8.2 ft./sec.) after a drop of 10 m (32.8 ft.). A weight G of 9,850 kg (21,715 lb.) is required, considering friction and additional moving masses.

<u>The starting process</u>.- The braked car is in the front end of the accelerating space. The current is switched on,

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*μ = friction coefficient between wheel and rail, Q = load on driving wheels.

the thrust of the drop weight and of the motors being taken by the air brakes. The carriage starts the instant the brakes are released. The start is recorded by a voltmeter on the control board. The motors are switched so that at the end of the acceleration run, they will have the power required for constant speed, as shown by the diagram in figure 12. At the end of the acceleration run, the weight in the well passes into a braking cylinder. The cable slackens and the released carriage continues to run at constant speed.

The shape of the weight, length of braking cylinder, spacing between weight and cylinder wall and the density of the braking liquid were determined by careful model tests, in order to achieve a reliable braking of the weight by the liquid.

<u>The braking of the carriage*</u>.- The carriage is braked over a distance of 50 m (164 ft.) by five sets of brakes.

1. The main brake is a Knorr air brake operating 4 pairs of brake shoes located behind the wheels and applied on both sides of the rail head. The carriage carries a compressed air tank for 30 complete applications. The tank is refilled by an air pump located in the upper end of the building. The brake is operated from a brake-control station in the front of the carriage.

2. If the air brakes are not operated in time, they are automatically applied by the action of a stop located near the rails, as soon as the carriage reaches the braking portion of its run.

3. At the same time the motors are reversed by an operator in the control station, located at that point of the run. The motors then act as electric brakes.

4. If, for any reason (e.g., damaged pipes) the air brakes do not function, a second stop, located close behind the first, releases a weighted lever which operates the control rods of the air brake through bell-crank levers, and applies the brake shoes with the same pressure as the air.

5. The final braking action is exerted 20 m (65.6 ft.) before the end of the tank by a rope stretched across the tank, running on each side over pulleys, and connected with two rubber cords of 70 cm^2 (10.8 sq.in.) cross section and

*The brakes and wheels were designed by A. Simon.

9.2 m (30.2 ft.) length. The carriage runs into the rope with a bumper, mounted close above the rails, and is braked with rapidly increasing force, which brings it to a complete stop in 20 m (65.6 ft.). A special slide shoe prevents the rope from imparting a reverse motion to the carriage after the braking.

<u>Control station and generator room</u>.- The control station, with the control desk from which the carriage motors are operated, is located above the generator room at the beginning of the braking portion. The generator room contains a Ward-Leonard set with a direct-current shunt generator of 94 kw. (320 kw. during 16 seconds) and a maximum tension of 630 volt, and an asynchronous 3-phase motor for 6,000 volt 3-phase alternating current and 110 kw. for n = 1,450 (approx. 350 kw. during 16 sec.). The set is started from the control station on the upper floor. The room likewise contains an exciting set of 25 kw. and the necessary resistances and switches.

The new test apparatus* and other equipment now under development will be described later.

List of firms participating in the construction:

1. Tank construction: Dyckerhoff & Widmann, Hamburg.

2. Building: H. Möller & Co., Hamburg.

3. Electric equipment: Siemens-Schuckert A.-G., Hamburg.

4. Car: Arado, Warnemünde.

5. Equipment, installation and instruments: Workshops of the Hamburg Shipbuilding Laboratory.

Index for Figure 1

<u>I. Front building</u>		<u>II. Tank building</u>	
1.	Director	A	Narrow tank
2.	Accounting office	B	Wide tank
3.	Drawing office	C_1	First control station
4.	Chief engineer	C_2	Second control station
5.	Photographic shop	D	Glass tank
6.	Blueprinting office	E	Forward trimming tank
7.	Files	F	Rear trimming tank
8.	Store	G_1	Sluice gate

*For those now in use, see "Versuche mit Gleitflächen," in No. 21 of the 1929 issue of this publication.

Index for Figure 1 (Cont.)

I. Front building

9. Welfare room
10. Lavatory
11 & 12. Scientific assistants
13. Control office
14. Conference room
15. Reception room
16. Hall
17. Office of seaplane tank
18. Office of cavitation tank and general management

II. Tank building

G_2 Sluice gate
H Seaplane tank
I Shallow tank
K Cavitation tank
L Large carriage
M Small carriage
N Trailer for shallow-tank tests
O Seaplane-tank carriage
P Wave-making mechanism
Q Adjustable bottom

III. Workshops

a Model shop
b Mechanical shop
c Carpenter
d Pump station
e Heating room
f Coke hold
g Switch room and electric shop
h High-tension room
i Transformer room
k Storage-battery room
l Filter room
m Lecture room
n Lavatory
o Workshop for seaplane tank.

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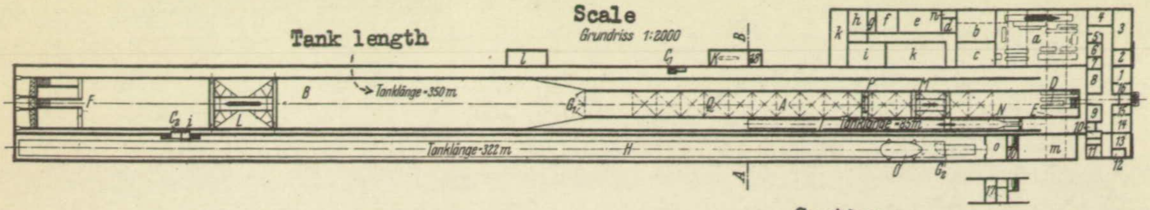


Multiply dimensions by 3.28083 to get feet.

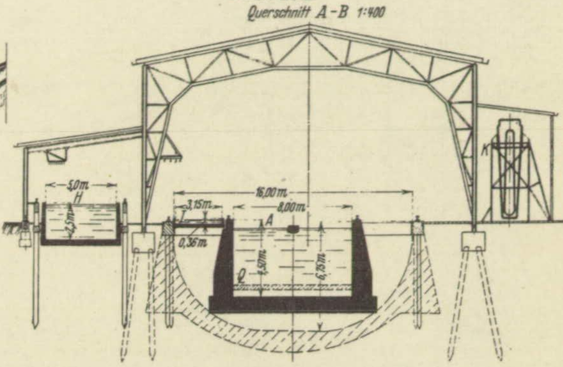


Figure 1

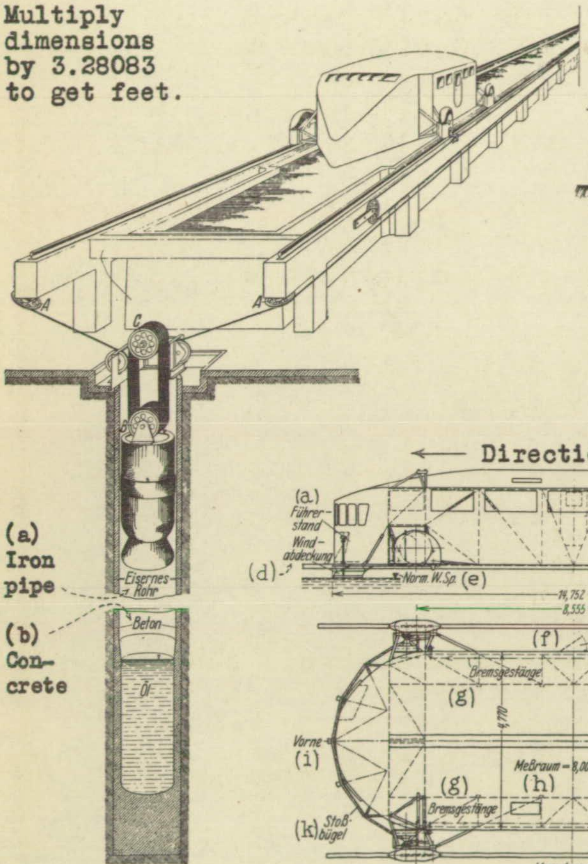
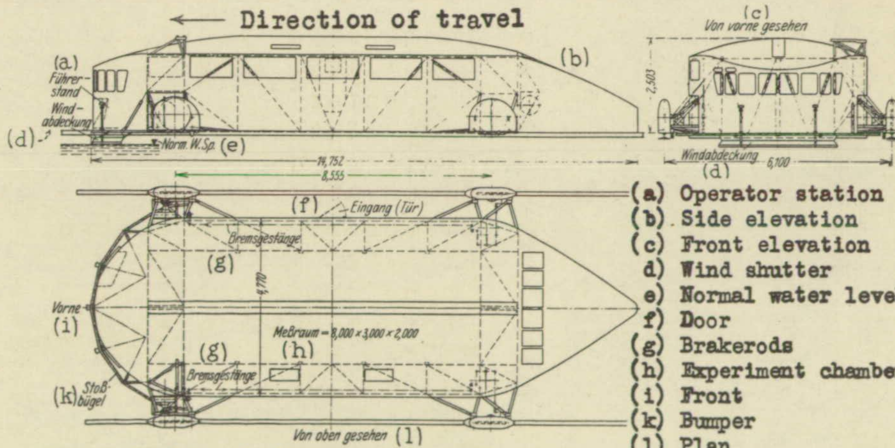


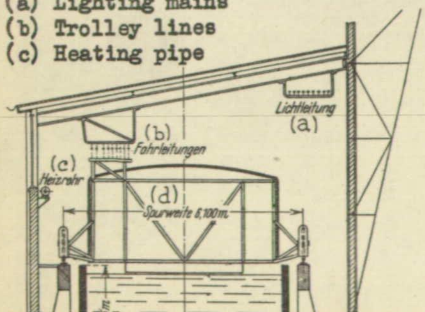
Figure 11



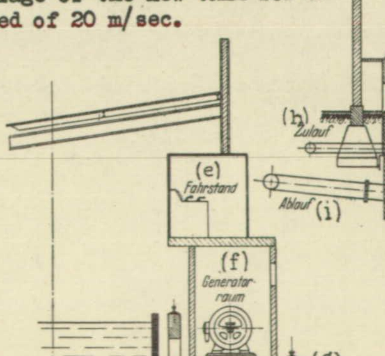
(a) Operator station
(b) Side elevation
(c) Front elevation
d) Wind shutter
e) Normal water level
f) Door
(g) Brakerods
(h) Experiment chamber
(i) Front
(k) Bumper
(l) Plan

Figure 7.-General diagram of the carriage of the new tank for a maximum speed of 20 m/sec.

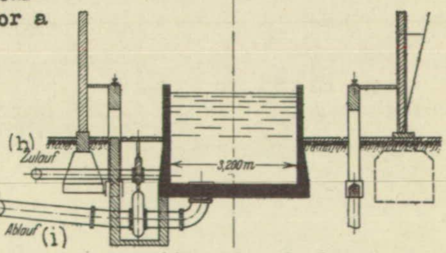
(a) Lighting mains
(b) Trolley lines
(c) Heating pipe



Main cross section
Cross section 1:150



Cross section through control station and generator room



Adjusting tank

(d) Track width 6.1 m
(e) Control station
(f) Generator room
(g) Large tank
(h) Inlet
(i) Outlet

Figure 2

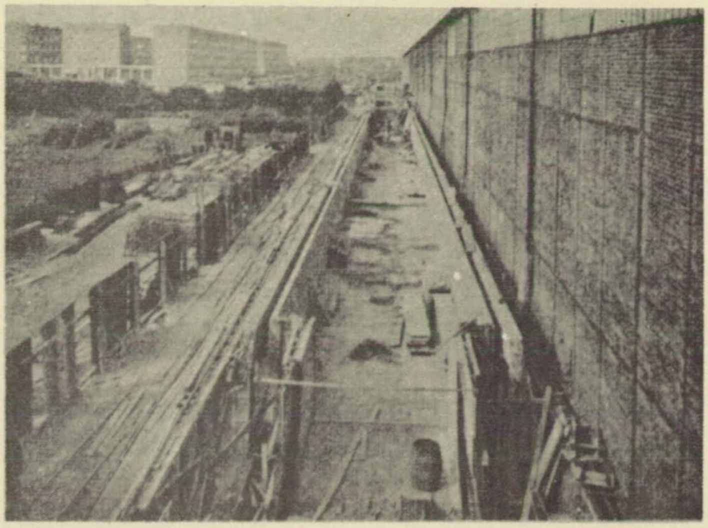


Figure 3.- Construction of the reinforced concrete tank, September 1930.

Figure 4.- Tank shortly before completion, May 1931.

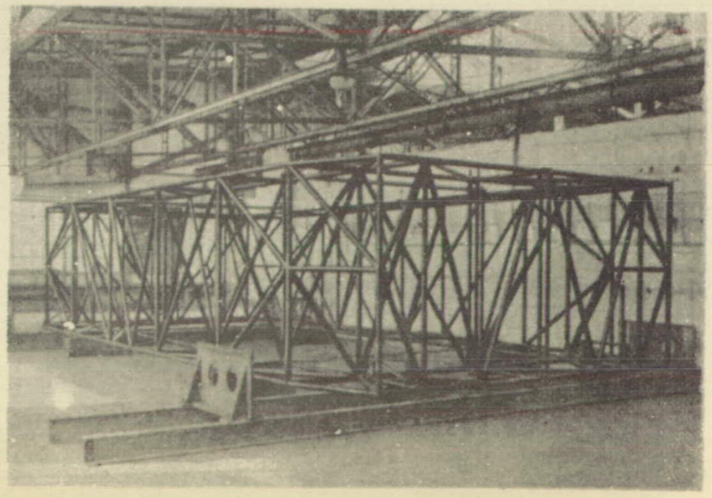


Figure 8.- Steel-tube carriage structure during assembly.

a, Velocity of tank well $v = \sqrt{gWT}$
b, Draft = 0.17 m, WT = 2.0 m, $\frac{WT}{Draft} = 11.76$
c, Extrapolated for draft = 0.178 m, WT = 2.5 m, $\frac{WT}{Draft} = 14$
d, Draft 0.07 m, resistance in large tank.
e, Draft = 0.07 m, WT = 0.7 m, $\frac{WT}{Draft} = 10$
f, Draft = 0.07 m, WT = 1.35 m, $\frac{WT}{Draft} = 19.3$
g, Draft = 0.07 m, WT = 2.0 m, $\frac{WT}{Draft} = 28.6$
h, Draft 0.17 m
WT = Water depth

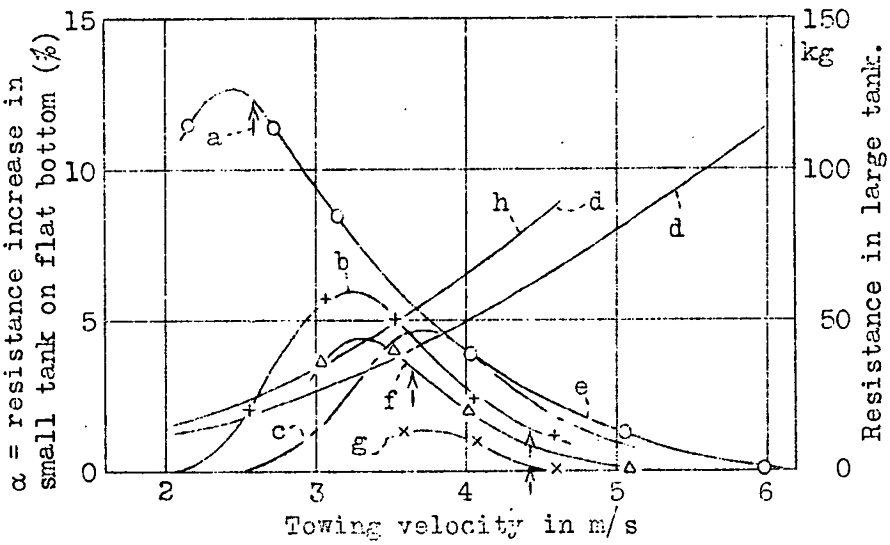


Figure 5

a, In tank 8 m wide and 2.5 m deep. Section 20 m^2
b, In unconfined water, large tank. Section 92.7 m^2

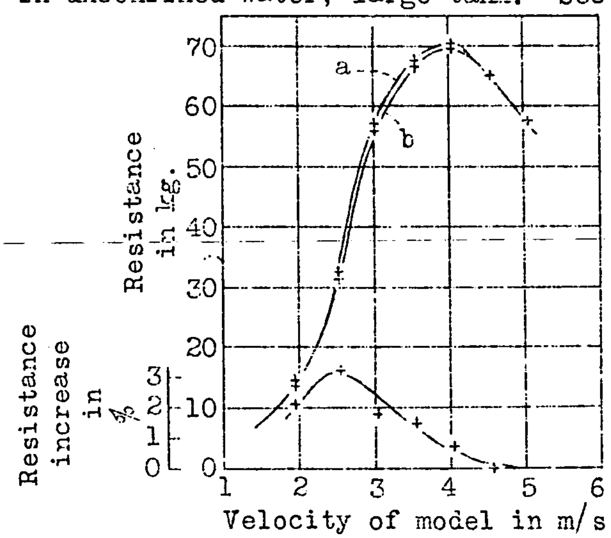
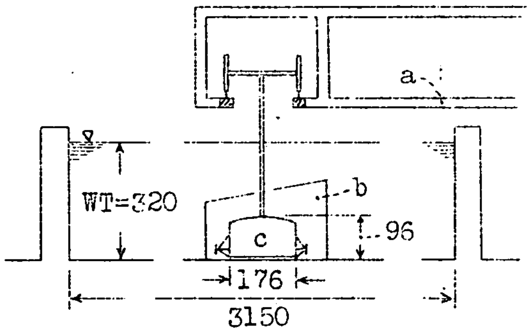


Figure 6

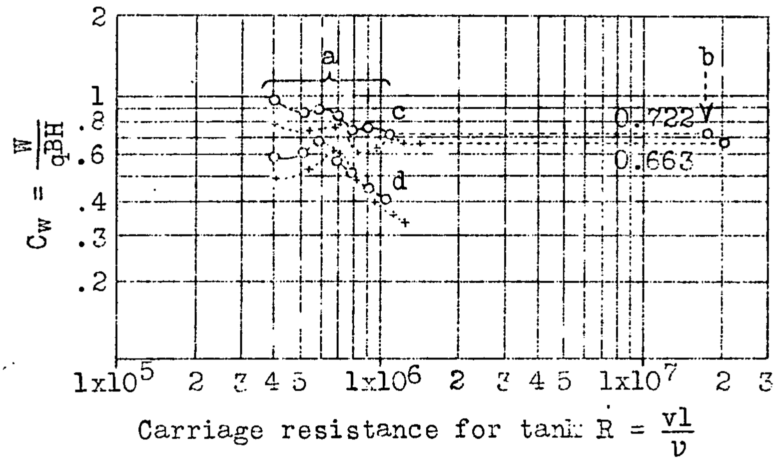


a, Carriage

b, Cross section of housing

c, Model

Figure 9



a, Model 1/25 in water.

b, Full-scale in air (max. value).

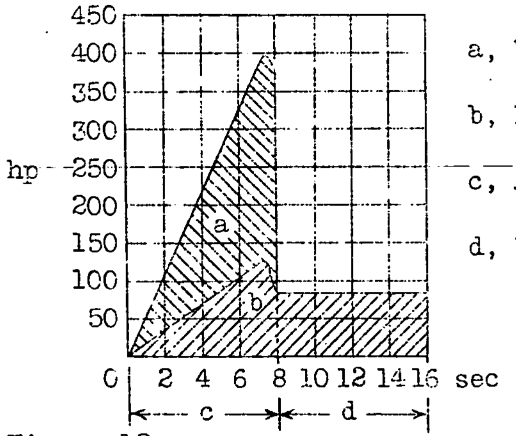
c, In housed section.

d, In open section of shallow tank.

o——— Design I

+----- Design II

Figure 10



a, Work of falling weight.

b, Electrical work.

c, Acceleration time

d, Velocity (or speed) 20 m/sec, constant.

Figure 12